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INTERNATIONAL SPACE RESEARCH
PERSPECTIVES OF COMMERCIALIZATION FOR GERMAN
INDUSTRY

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16. Abstract After a brief overview of space flight, the author discusses West German contributions to satellite mapping, communication satellites, navigation, Spacelab, diffusion under weightlessness, crystal growth in space, metal bonding, and biochemistry. The future of the research in the space station is analyzed.					
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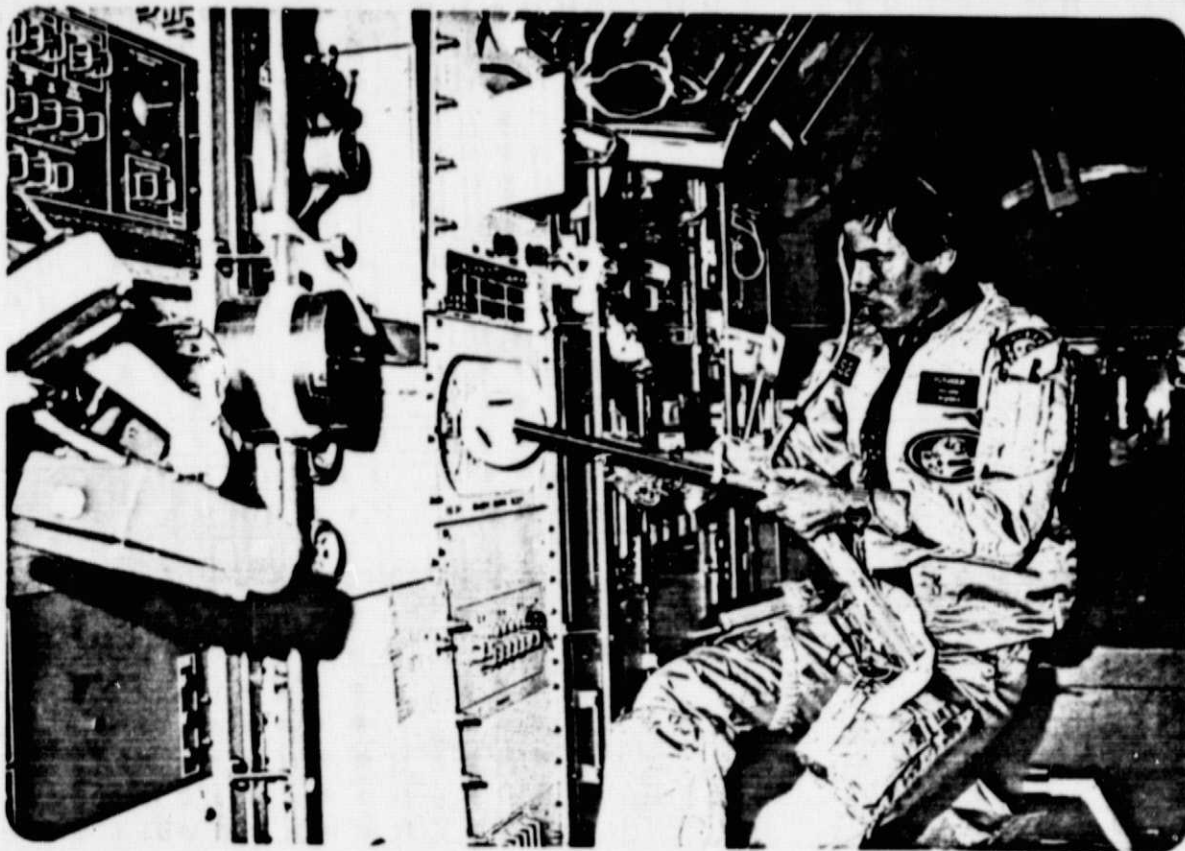
PERSPECTIVES OF COMMERCIALIZATION FOR GERMAN INDUSTRY



Lecture on the occasion of the meeting of the
"Committee for the Politics of Research and Science" of the BDI
October 19 1984 , Science Center, Bonn, by
Prof. Dr. H.L.Jordan, President of the Board of the DFVLR

DFVLR: German Aerospace
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Title picture: Payload expert Dr. Ulf Merbold changing a test in the materials laboratory during the first flight of the Spacelab.

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When space travel is mentioned, in many cases the first thing that comes to mind is the spectacular picture of a rocket firing or, more recently, of the American Space Shuttle. At your meeting today you have given me the opportunity to report to you the potential for the use of space travel in the industrial sector. You all know of the decision of the American President to carry out the construction of a permanent space station by 1992 and in connection with that, his invitation to the allied and friendly nations to participate in this program. The Federal government of West Germany now faces the difficult decision of how to reply to this invitation. The government needs, amongst other things, an opinion from the industries not involved in space travel as to the technological effects of participation or non-participation.

I would first of all like to look back and give you a brief overview of the development of space travel and its application up to the present day and then take a look at the potential effects of further development on industrial applications.

The dream of mankind to fly and to reach other planets or stars is probably as old as mankind itself. The realization of this dream became the privilege of this century. The first successful flight of a rocket outside the earth's atmosphere took place on October 3 1943 from Peenemuende with the A4 rocket which under the name V2 achieved tragic fame. After the Second World War the USA and the USSR continued with the further development of rocket technology. On October 4 1957 the first artificial earth satellite, Sputnik 1, was successfully launched, which signaled a breakthrough into a new era. On April 12 1961 came the memorable flight of Yuri Gagarin, the first human in space, and we all remember well July 20 , 1969 when Neil Armstrong became the first person ever to set foot on the moon.

At this point in time the use of space travel in the scientific and technical area had already progressed a long way. As in all past centuries, astronomy, or in more general terms, the science of the universe, was the pace-setter for new technological discoveries. Many scientists in this discipline recognized the possibility of gaining new observation territory outside the earth's atmosphere in spectral areas that had not previously been accessible through the atmospheric filter. The construction of satellites and probes for this purpose initiated technologies that we take for granted today and that have changed our daily life in many ways in their applications on the earth. Among these technologies are:

- the development of robotics (Fig. 1)
- the miniaturization and increased reliability of electronics
- data transmission technology
- the development of camera technology

and many other areas whose spin-off cannot be specifically detailed but which have had an effect. The picture of our earth has changed since the first historic photographs were taken by the Lunar Orbiter on October 23, 1966, when the earth appeared before our eyes as a small heavenly body seen from the moon (Fig. 2). Before this, extensive pictures of the earth had been taken by the Mercury and Gemini capsules, the first steps towards observation of the earth and the atmosphere. Today the satellite picture used for the weather report on television has become a reality taken for granted.

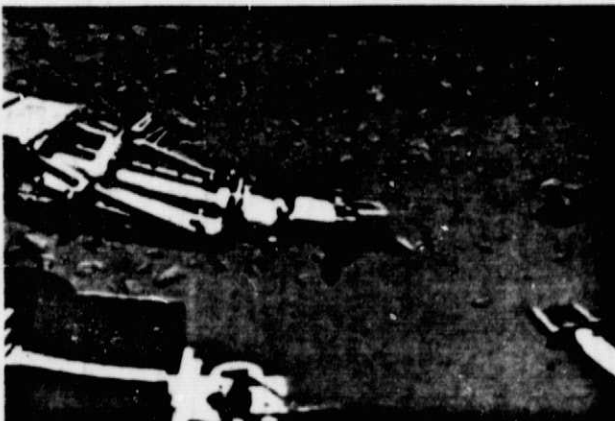


Fig. 1: Scraping arm of the NASA Viking Landing Craft as an example of remotely-guided robotics (NASA)



Fig. 2: First historic photograph of the earth taken from the circumnavigation of the moon on August 23, 1966 (Boeing)

3. OBSERVATION TECHNOLOGY

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Some of the areas of use for observation technology are national monopoly areas such as atmosphere and weather services and environmental protection, and also commercial areas such as prospecting for mineral deposits, cartography and the gathering of prediction data for agriculture and forestry. The methods and sensors developed for these purposes on a national level can be used in the future for the tasks of development assistance politics. From an economic point of view, this represents an interesting combining of the performance of international obligations with expenditures in the national area. To fulfill these tasks the DFVLR has taken over the function of a German space information center. The projected goals include both a technical and a scientific contribution and comprise activities that range from the reception and creation of data to preparation and processing, and analysis and interpretation. The space information data center supports primarily German users from the areas of science, government ministries and authorities, and industry. For reimbursement of expenses it cooperates both in purely national and in bilateral and international activities and functions as a central information agency for tasks of this kind within the DFVLR and in particular also in relation to the ESA as the "national point of contact" (NPOC).

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To fulfill this task, the space information data center plans, sets up and operates the necessary systems and facilities.

The need-oriented, continuous further development of these systems and their adaptation to the current state of technology as well as to the newest platform 1 sensor combinations are seen as a condition for an effective "marketing" of space information. This is being done by, amongst other things, informing and educating users and above all by participating in use-oriented studies and pilot projects. Examples of this are the satellite image map of Bavaria (Fig. 3) and a geometrically enhanced NOAA view of central Europe (Fig. 4).



Fig. 3. Satellite image map of Bavaria (DFVLR)

Key: 1 detection system; 2 flying altitude; 3 orbit in-
clination; 4 spectral ranges; 5 ground element;
6 reception and processing; 7 digital processing;
contrast enhancement, natural coloring (green
version), composition from 8 individual views
each with an image area 185 km x 185 km, and
enhancement by the digital image processing
system (DIBIAS) of the DFVLR; 8 publisher

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Fig. 4: Geometrically enhanced photograph of central Europe (NOAA)

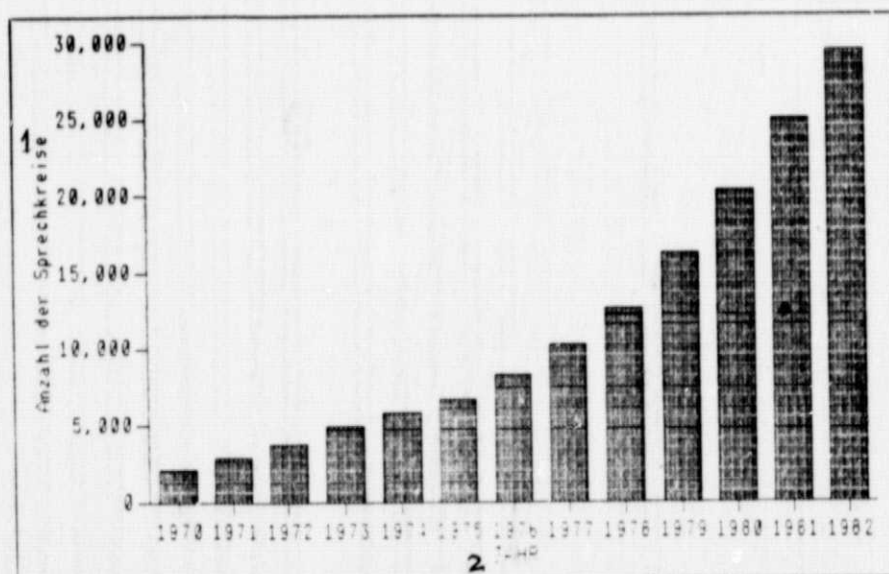


Fig. 5: Full-time usage of INTELSAT long-distance telephone connections (Atlantic, Pacific and Indian altogether).

Key: 1 number of telephone connections; 2 year

The application areas of satellite communication and navigation are at present the main commercial users of space travel. Since Intelsat was established in the 1960's and initiated its intercontinental information transmission via satellite, the use of space travel for communication has progressed enormously. Relative to the Traditional use of transmission by large bundles of telephone connections, usage has increased many times in a few years (Fig. 5). New applications such as the transmission of television pictures of studio quality have since been added. With the further development of communication and satellite technology, new application areas have been opened:

In the case of stationary services the regional transmission networks have been added, and then the special services for business communication:

- Mobile radio communication began with ocean radio via satellite and has developed today in the direction of flight radio and mobile land applications, such as automobile telephones. The improved performance of satellites now makes possible the transmission of television programs directly to the viewer. Orientation satellites facilitate highly exact position readings for ocean, land and air traffic. New measurement methods are possible for geo-scientists.

The increase in the use of satellite communication and the resulting technical limits made it necessary for further developments to be made in the area of satellites and, increasingly, in the communication technology components. The improved performance of the satellites, mainly in their electrical performance but also resulting from larger antennas, can be deduced from the increase in satellite weights (Fig. 6). A further increase in the transmission capacity of the satellites, required by the increasingly limited useful orbit, was achieved by constant improvements in communication technology. The resulting shift in the percentage of components and the associated costs of a communication satellite system is leading at present to a shift in the roles of the space travel

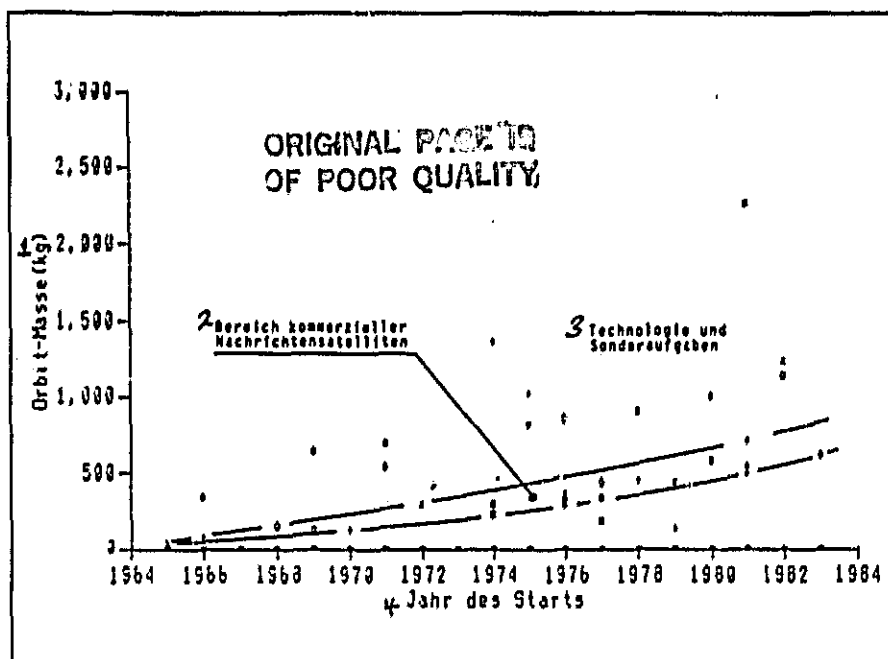


Fig. 6: Development of the orbit weights of communication satellites (kg)
 Key: 1 orbit weight (kg); 2 range of commercial communication satellites; 3 technology and special tasks; 4 year of launch

industry in the direction of the communication industry.

The commercial market for the communication satellite systems is, however, like the communications market in general, heavily regulated. In connection with the dominant role of international corporations in international communication enterprise and based on the geographic facilities in the USA and their military use, the industry has particular marketing possibilities there. National and European funding has been able, however, to reduce the disadvantage of the European industry in the competition. The availability of our own European carrier system has contributed significantly to this trend (Ariane).

5. AREA OF REDUCED GRAVITATIONAL EFFECTS

On November 28, 1983 was launched for the first time the Spacelab developed and built in Europe aboard the American Space Shuttle for a flight into space. In addition to experiments in the classic areas described up to that time for space travel utilization, studies were also carried out before the eyes of the public in these disciplines:

- materials science and technology
- operations technology
- bio-sciences
- pharmacy

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In spite of the great publicity received by this event in the media in Europe, the extent of these first experiments was not fully understood by the public. This is certainly not the fault of the observer, but the participants in the space flight have an obligation to make this up, which is one of the objects of today's lecture. I will later go into more detail in this area.

Before I go into a further discussion of the new use areas of reduced gravitational effects, I would like to explain two concepts that will keep cropping up. The side programs TEXUS and MAUS are carried out within the framework of the national space travel program. TEXUS stands for a rocket program in which, after the rocket has finished burning, experiments can be conducted for about 6 minutes under free-fall conditions, i.e. under reduced gravitational effects. In the side program MAUS, autonomous experiments can be carried out in closed containers in the payload bay of the Space Shuttle during the entire flight time of a shuttle mission, i.e. for up to 10 days.

What does reduced gravitational effect mean, what are the results and what industrial applications can we anticipate will be derived from it?

Man is accustomed from childhood on to live and work under the conditions of the earth's gravity. The velocity of the earth, $g = 9.81 \text{ ms}^{-2}$, is present everywhere and is the basis of our experience. This value decreases from the center of the earth calculated with $1/R^2$ (Fig. 7).

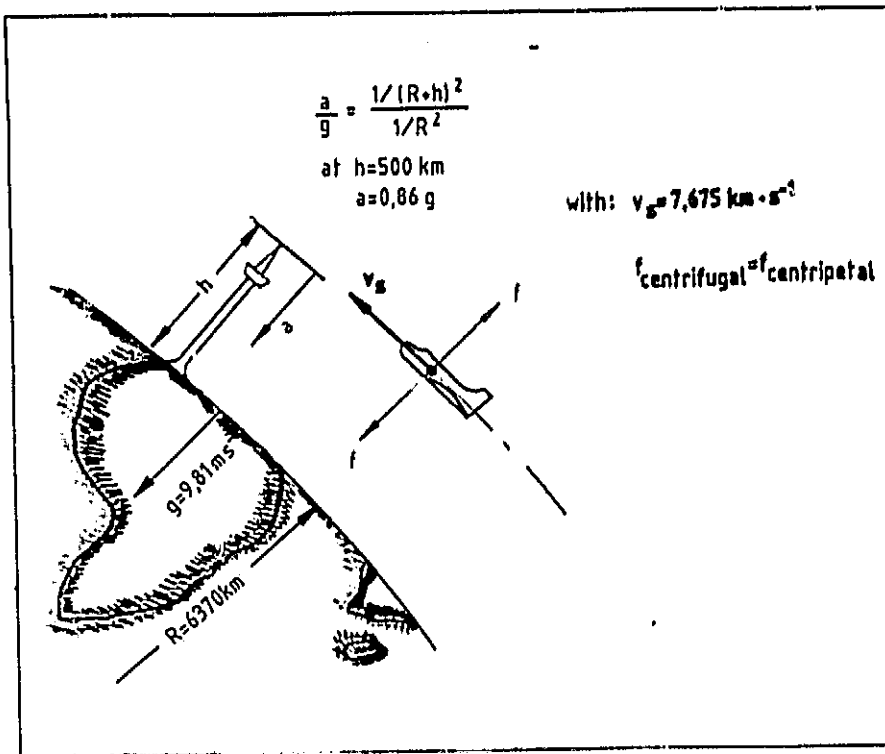


Fig. 7: How the "weightless" condition occurs in space flight.

If we were in a position to build a tower 500 km high, at its peak we would experience a decrease in the value of g of only 14%. However, other physical conditions apply in the case of a space vehicle that orbits around the earth without being driven. A certain speed must be achieved for each orbiting altitude, so that at the center of gravity of the space vehicle the orbiting force is equal to the earth's gravitational force, i.e. they compensate each other and produce the state of weightlessness. The ideal value of $g = 0$ cannot be achieved, because of deviations from the ideal value of the orbiting altitude and speed and from the distance of the observation point from the center of gravity of the system as a whole, because of the braking of the spacecraft and the final, though low density of the gas molecules in the environment, and because of Newtonian forces, inhomogeneities in the earth's magnetic field and the uneven shape of the earth. Therefore one refers to the area of reduced gravitational effect, micro-gravity or μg . Real-

stic values for a spacecraft such as the Space Shuttle/Spacelab are at a residual acceleration of 10^{-3} to 10^{-4} g.

AS a result of the effects of reduced gravitational force there are consequences for materials in liquid or gaseous form. There is an exclusion or considerable reduction of:

- sedimentation
- convection
- hydrostatic pressure
- potential energy form,

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which permits combinations of forces to become visible that are masked by the force of gravity under conditions on earth:

- flows through surface tensions on the liquid-gas interface and also on the liquid-liquid interface in the case of non-miscible liquids.
- wetting behavior of liquids on walls and the formation of menisci.
- interface dynamics in all combinations of aggregate conditions.

Liquid physics and flow mechanics are the basis of all analyses of the use of the μ g environment. Each material being processed goes through a liquid or gaseous phase - in the case of mixtures of two or more substances, at least one of the components. Each process requires a temperature gradient which in its turn produces corresponding forces as a result of the physical properties of the substance.

Current studies in this area of research have the objective of developing bases for the industrial use of this new environmental parameter that is not reproducible on earth.

Four possible areas of industrial application have been identified in this still somewhat speculative area:

- Manufacture of materials of interest from a physical/technical viewpoint that can only be manufactured under conditions of reduced gravity because of the physical characteristics of the substances (III-V and II-V alloys). There is also the possibility of floating melting processes.

- manufacture of materials that can only be produced in the absence of convective flow in the required homogeneity.
- Execution of tests to improve methods used on earth, insofar as the earth's gravity does not permit an individual analysis of the various influencing parameters.
- Execution of processes that are more economical to carry out under space flight conditions.

By way of example, in the following sections will be given some results from experiments that have flown in space and that have applications in the industrial sector or innovative techniques from medical research in the clinical area.

5.1. DIFFUSION PROCESSES

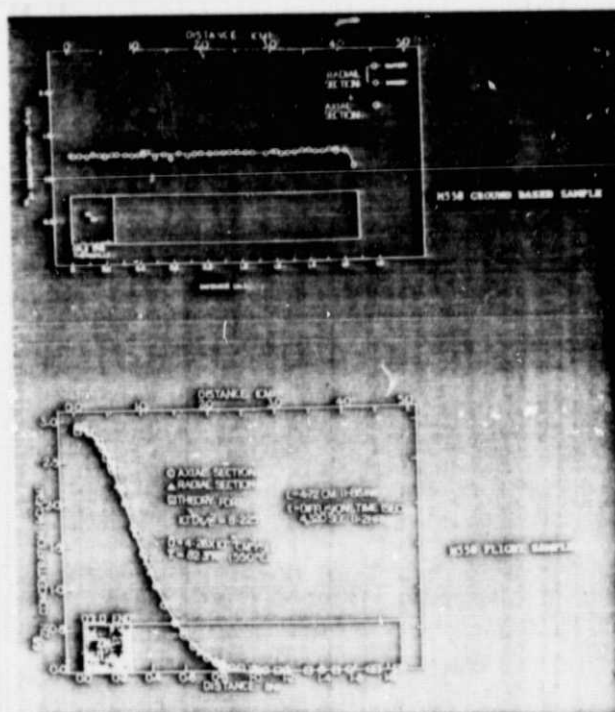


Fig. 8: Diffusion of radioactive ^{65}Zn under conditions on earth and under the effects of reduced gravitational force (Ukanwa). The line drawn through in the flight experiment corresponds to the theoretical profile for a stationary melt.

To study the flow relationships in a melt under micro-gravity conditions, an experiment was carried out by Ukanwa on the self-diffusion of zinc. The arrangement is shown in Fig. 8. Cylindrical samples of zinc with a segment of radioactive ^{65}Zn were melted in graphite ampoules on earth and during the Skylab flight in a gradient oven. The axial temperature gradient of the melting was about $50^{\circ}\text{C}/\text{cm}$; the melting was kept for about an hour at about 130° above the melting point and then solidified. Figure 8a shows the distribution in the laboratory experiment, and Fig. 8b the flight experiment. On earth the melting is largely homogenized by diffusion and convection. Under micro-gravitational conditions one finds a concentration profile for ^{65}Zn that agrees within the measurement exactness with the profile that can theoretically be expected to occur for a stationary melt (curve drawn in Fig. 8b). This finding shows clearly that at a residual acceleration of 10^{-3} to $10^{-4}g$ convection can be disregarded in the melting process.

This finding is supported by experiments in crystal growth. Experiments on diffusion in salt meltings are being carried out by Richter of the RWTH in Aachen in the German Spacelab Mission D1 in 1985.

The diffusion coefficients are important substance data for technical analysis processes. At present salt meltings are in the forefront in many technical developments: the manufacture of pure metal, the aluminum industry, energy conversion and storage, surface treatment, etc. Because of the measurement problems in the laboratory, there have very few studies in the literature up to now. For the proposed D1 experiment on diffusion in the melting process, an important preparatory experiment was carried out in the TEXUS program. The result of this was that under conditions of no gravity spectacular success can be achieved in producing sharp diffusion boundary layers at high temperatures as the optimum starting condition for diffusion.

The data anticipated from this experiment can be used to understand crystal growth under μg conditions and to interpret the strong growth of protein crystals. They can also be used as a reference experiment for ground-breaking studies in the laboratory on further technical applications.



Fig. 9: Ga-doped Ge crystal grown according to the Bridgeman method. This experiment was carried out under the TEXUS project during the climbing phase (left half of picture) and under μ -g conditions (right half of picture) (Walter and Favier).

By means of a rocket experiment in the TEXUS project, Walter and Favier were able to provide proof of the possibility of producing homogeneously doped semi-conductors under conditions of micro-gravity (Fig. 9). Germanium crystals doped with gallium were produced by the Bridgeman method. The experiment was done as follows: The setting process was initiated before the launch of the rocket and was continued without interruption during the launch, the climbing phase, the free flight phase and the re-entry into the atmosphere until the landing. During the climbing phase and the re-entry, accelerations occur up to 20 g. These cause in turn corresponding convection flows which, however, with the geometry chosen fade within a few seconds. The flight sample was about 4 cm long and was secured between two 1 g reference samples. It shows doping bands caused by convection that can be directly correlated with the vari-

ous flight phases. Figure 9 shows the transition between the de-spinning phase and the micro-g phase. During de-spinning strong convection occurs. In this area the sample is correspondingly unhomogeneous. The material set during the micro-g phase appears to be completely homogeneous. The equidistant sharp bands in this section of the sample were produced artificially by flow pulses lasting 50 ms and at intervals of 4 s. These markings make it possible to measure the microscopic growth rate and the geometry of the interface at any point in time.

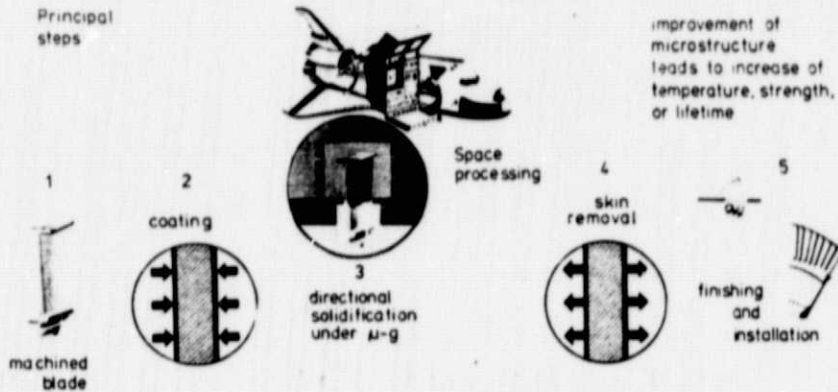
To understand crystal growth from melts, which is particularly emphasized here, an adequate knowledge of the properties of melts and the processes involved in melting is required. Since appropriate crucible material is lacking for many high-melting and chemically reactive materials, the potential exists for conducting physical and physico-chemical studies of floating melts. In addition, floating melts can be used to study homogeneous or heterogeneous nucleus formation phenomena.

From this could possibly be derived methods of crystal growth from super-cooled melts. The shaping of floating melts using acoustic, electrical or electro-magnetic forces is of fundamental interest. The potential exists here also for new technical methods, for example, processes for the manufacture of mono-crystalline layers from melt layers.

Because of the absence of density convection, under u-g conditions it is possible to produce homogeneous and highly doped semiconductor crystals and alloy crystals. Of particular interest are various ternary or pseudo-binary systems, such as (Ga, In) As and (Pb, Sn) Te, and alloys such as Ge-Si. In the case of eutectic alloys there has so far not been any clear experimental proof of an improvement in quality resulting from manufacture under conditions of micro gravity. A basic condition for the production of eutectic materials is a planar solidification front. Corresponding experiments were carried out during the first Spacelab flight with nickel-antimonide/indium-antimonide.

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SKIN TECHNOLOGY



Applications:

- means of performing basic solidification experiments under weightlessness (thin skin - high $\Delta T/\Delta x$)
- economic space manufacturing of high value products

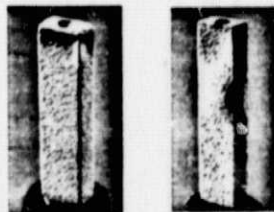


Example:
eutectic superalloy
 $\gamma/\gamma' - \alpha$
Ni(Cr)/Ni₃Al - Mo

TEXUS I and II



10^{-4} g-processed samples



Matrix:
Ni-base alloy

Skin: Al_2O_3
1-50 μ m

Further experiments
MAUS, FSLP, D1 -
Spacelab missions

Earth processed sample



M.A.N. mtu BMFT/DFVLR

Fig. 10: Principle of directional solidification of eutectic alloys according to the skin technology of M.A.N. New Technology (Sprenger)

5.3. METALS AND BONDING MATERIALS

Another interesting area of industrial application is the production of highly stable turbine blade from directionally solidified eutectic alloys (Fig. 10). Sprenger of the MAN New Technology Co. has done ground-breaking work here. Preparatory experiments were done within the framework of the TEXUS program and these have already produced positive results. Because of the premature failure of the oven on board the Spacelab, unfortunately the experiment could not be completed on the first mission. This experiment, known under the project name of skin technology, is an attempt to coat a turbine blade manufactured on earth with a thin skin. When this process is carried out under reduced gravitational effects, because of the absence of hydrostatic pressure it keeps its shape. Thus the blade material can be melted on the inside and directionally solidified. /13

Two other research areas relating to metals and bonding materials should be mentioned that are important for production processes on earth:

- dispersion hardened materials
- amorphous metals.

The intention is not to produce these materials on a large scale under weightless conditions, but to gather new information on how to improve the materials and production methods on earth.

Relative to the dispersion hardened materials this means specifically the study of the behavior of particles or liquid secretions in the path of an approaching solidification front. Since sedimentation and uplift do not occur, the conditions that cause the incorporation of the "particle" into the solidification front can be studied exactly. The first experiments in this direction were successfully carried out in the German TEXUS program (Fig. 11).

In association with amorphous metals the question automatically arises of the super-coolability of metallic melts, or nucleus formation is mentioned. In order to prevent this, cooling is done on

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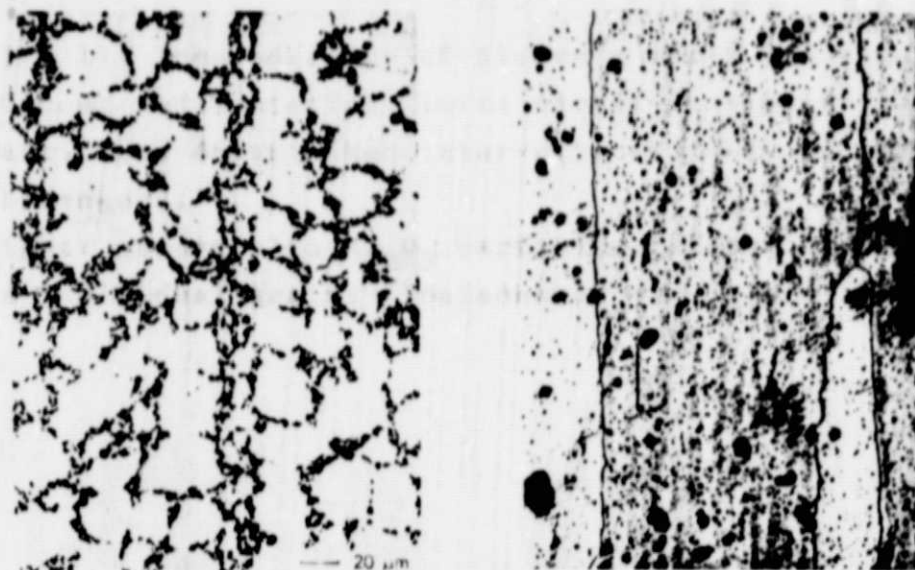
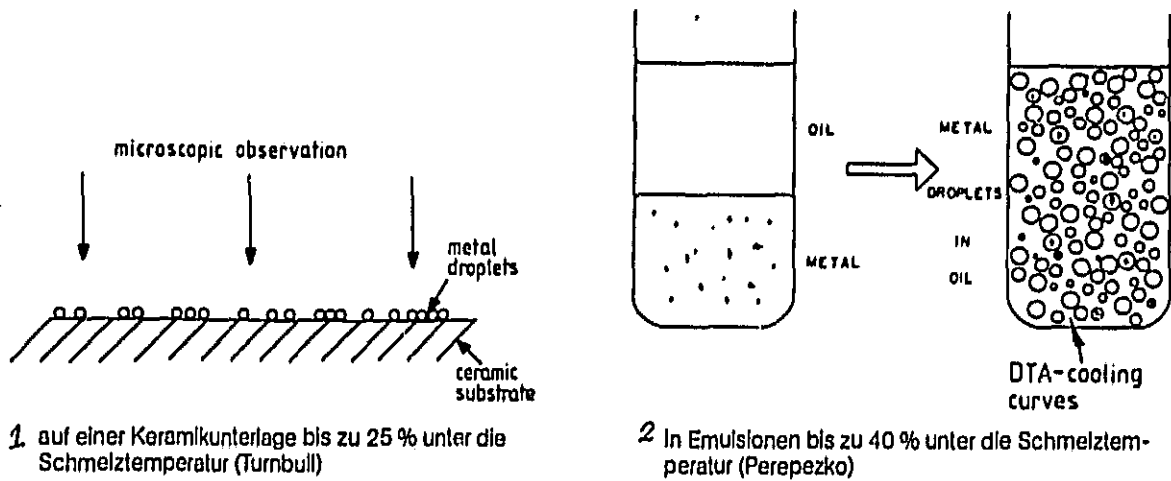


Fig. 11: Incorporation of discrete particles into a metal matrix without sedimentation; left: nickel-base alloy (N1 738) with Y_2O_3 particles, distributed inter-crystallinely on the grain surfaces (Sprenger); RIGHT: copper with Al_2O_3 particles, distributed trans-crystallinely in individual grains (Poetschke).

earth with extremely high cooling levels ($10^6 Ks^{-1}$), which has the effect that one can only solidify amorphously very thin layers or very small particles. Only by compaction of these layers/ particles can one produce a "massive" material.

Another path in this direction consists of container-less melting and solidification of fairly large melt volumes under weightless conditions, known as containerless processing. Since there is no melt/crucible contact, with careful processing the heterogeneous nucleus formation can be eliminated and the melt can be correspondingly sub-cooled. It is still not clear how far - whether, by eliminating homogeneous nucleus formation, as far as the amorphous state. At any rate, the most recent measurements in the earth laboratory, where gallium was super-cooled to $0.58 T_m$ and bismuth to $0.41 T_m$ (T_m = melting temperature in kelvins), give the hope of inte-



3 und die Ergebnisse:

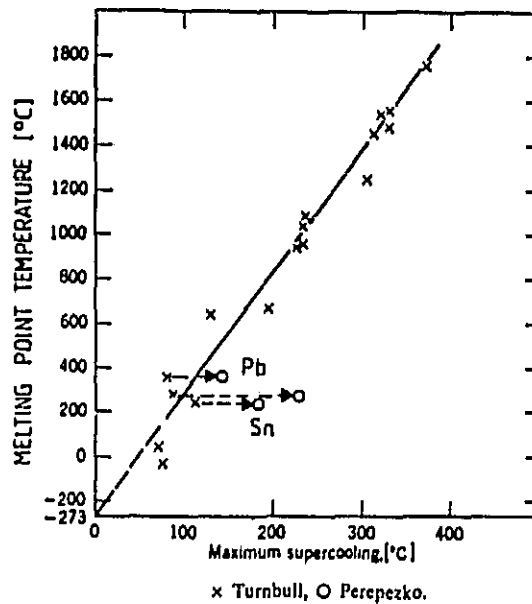


Fig. 12: Techniques for observing maximum supercooling in small metal droplets.
Key: 1 on a ceramic substrate up to 25% below the melting temperature (Turnbull); 2 in emulsions up to 40% below the melting temperature (Perepezko); 3 and the results

resting results (Fig. 12). The common value for the supercoolability of metallic melts is 0.18 to 0.10 T_m .

5.4. BIOCHEMISTRY/BIOTECHNOLOGY

Another promising field of application is biochemistry/biotechnology. This discipline is at present enjoying great expansion both in earth and space processes.

Prof. Hannig from the MPI for biochemistry in Martinsried has been the forerunner in research into the effects of gravity on biotechnical processes. In 1975 he studied on the Apollo-Soyuz mission the electro-phoretic separation of living erythrocytes, bone marrow cells, spleen cells and lymphocytes and, in spite of technical difficulties, he achieved 4 to 7 times increased rates of success.

This method has been further developed in the USA, where the Ortho Pharmaceutical Co. is operating a 200 x 45 cm² free-flow electrophoresis cell for the separation of proteins and cells producing pharmaceutical substances (e.g. kidney cells for urokinasis and erythropoietia) on the present Shuttle missions. No new figures have been given on the results that might ultimately be achieved in space. So far about \$200 M in private funds have been invested in this development by the participating industries. Because of this they are no longer obliged to make their findings public. The latest figures from the fall of last year show an approximately 700 times greater output but also, far more important, the purity of the separated product is increased by a factor of 4 or 5. It can already be determined that electrophoretic separation techniques work better in space (Hannig 1984) and that there are indications of new separations that were previously impossible on earth (P. Todd, Penn. State Univ.).

Since 1982 an electrophoretic apparatus has also been in operation in the the Russian Salyut station, in which, amongst other things, flu virus antigens as reference standards for vaccines or antibiotic-producing micro-organisms are being separated and proteins produced by genetic technology are being purified. The application possibi-

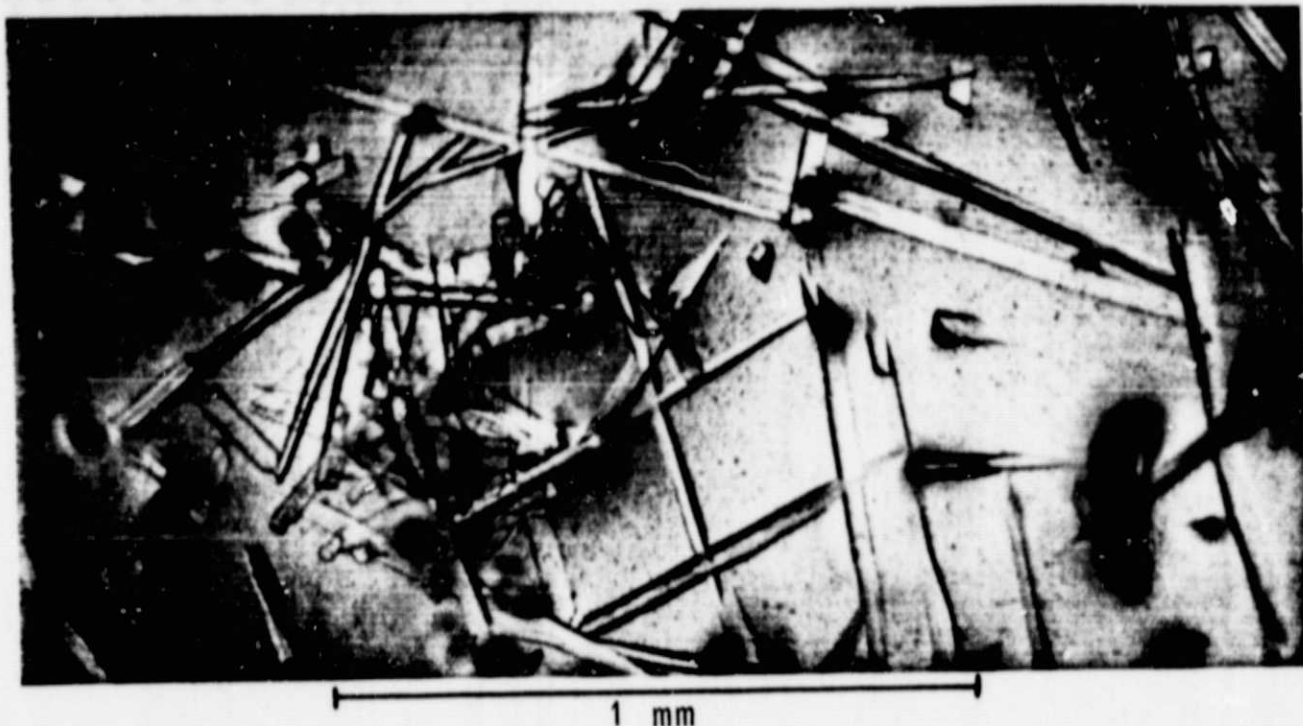


Fig. 13: A selection of β -galactosidase mono-crystals, grown under conditions of micro-gravity (Littke).

lities for electro-phoretic experiments in space are also being tested in Japan and the ESA member countries.

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Another application area is related to the growing of large protein crystals in space for the purposes of structural and functional clarification. After Prof. Littke of Freiburg succeeded in growing in Spacelab 1 (1983) (Fig. 13) crystals of the enzyme lysozyme selected as a model and beta-galactosidase from salt solutions, with a volume increase of up to 1000 times more than in control experiments (the use of alternative methods on earth, e.g. gel crystallization, to suppress convection are not successful with many proteins), suggestions have been made nationally and internationally for a whole series of interesting proteins whose structure is still unexplained and which could be studied in space. Membrane proteins and industrial enzymes are particularly important for pharmacology and industry and several companies have already expressed interest in these.

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Because of the prevalent weak bonding forces in the fields of organic and bio-chemistry, a number of examples can be found there for advantageous testing in a weightless condition. Two others will

be mentioned here:

- crystallization of synthetic materials used as electrical conductors (e.g. for optical information transmission of thin film technology), which are at present being studied by the 3M Corporation.
- manufacture of perfectly spherical latex balls in the diameter range impossible to achieve on earth of 3 to 100 μm (as reference standards). Units of 15 million balls with a diameter of 10 μm from one of the last Shuttle missions can already be purchased at the NBS for a price of about \$300.00.

5.5. BIO-SCIENCES

The studies of the organ of equilibrium will be discussed as examples from the area of bio-sciences, which are a combination of the disciplines of biology, medicine and botany.

For studies of the function of the equilibrium apparatus and space orientation under weightless conditions the sled experiment package was developed for the first Spacelab flight. These studies were directed by the principal investigator von Baumgarten from the University of Mainz. The most important part of this package is the vestibular helmet (Fig. 14) with the optokinetic and caloric stimulation unit, infrared camera and physiological sensors. This helmet, which was developed in Germany, will be used for the first time together with the ESA vestibular sled for linear acceleration in the first German Spacelab mission D1.

While the analysis of the flight data from the first Spacelab flight of the ESA is still in process, an initial finding from the subsidiary area of calorics shows that the interpretation of the standard test for caloric nystagmus will probably have to be changed, i.e. clinical knowledge has been expanded here.

The accompanying ground program, or the development of the flight equipment gave the impetus for the further development of clinical diagnostics and study methods in the area of eye movement distur-



Fig. 14: The helmet developed for the study of the vestibular organs under reduced gravitational effects is being used at present under clinical conditions on earth (von Baumgarten).

bances and dizziness (posturography, eye observation, air calorics). /14
In some cases, the vestibular helmet developed for the Spacelab flight can be used under clinical conditions on the ground with patients with diffuse dizziness symptoms to determine vestibular assymetries or a disease of the otolith organ.

In the future the human physiology experiments (including heart and circulation) in space can be expected to broaden our knowledge of the theoretical basis for the causes of travel and space sickness and this can then be used to develop remedies.

5.6. EXAMPLES OF INDUSTRIAL PARTICIPATION

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Two examples will be given for the area of space studies for applications on earth.

At a NASA-AIAA symposium in February 1984, Jim Graham of the John Deere Co., manufacturer of large tractors, agricultural machinery and construction equipment, reported that 25% of their business consisted of grey-iron casting. The company was looking for a way of achieving better results with this material relative to stabili-

ty, toughness and workability, which are connected with the form in which carbon is given off. By chance he engaged in conversation at a cocktail party with a NASA colleague who told him about the experiments in materials research in space. From this developed a cooperative venture that was so successful that, after the initial short-term tests, experiments are now being prepared for the Space Shuttle.

The transportation of powders and granulates is a very energy-consuming problem in many industries. To clarify the specific phenomena of the transportation process, Prof. Muschelknautz, formerly of the Bayer Co. and now at the Technical University of Stuttgart, carried out an experiment on the two German SPAS missions which was very successful on the second attempt and has produced considerable information in this area.

The at first utopian sounding idea of carrying out processes in space more economically than on the ground is confirmed by the McDonnell Douglas Co. and Johnson and Johnson. According to their calculations, if the processing apparatus remains in constant orbit and only the materials being processed have to be transported into space and back, the investment required and the operating costs will be lower than for the same production volume on the ground.

These examples of possible industrial applications for space travel may be considered merely suggestions that can lead to study of other possible techniques. It is not possible in a short exposition to cover the entire spectrum of the results already available today and the activities in preparation. This is the task of scientific-technical conventions that are already firmly established. These are of interest to an ever-growing scientific public - and naturally are also subject to scientific criticism, to which we must always be open. Therefore it is precisely at this stage that the continuation of the program must be assured. μ -g research is meanwhile being accepted as a new scientific direction from which long-term innovative results can be expected - providing the impetus for both fundamental research and for the study of application and industrial problems.

5.7. SUMMARY OF THE μ -g PROGRAM

In addition to its direct scientific goals, the u-g program initiates a branch of research that requires and supports to an unusually high degree both interdisciplinary and international cooperation. Significant new technological developments in this research have resulted from the close cooperation with the space travel industry which has reached a high degree of technical expertise in Germany.

Intensive continuation of the u-g program is required by both basic research, in the sense of "just" gaining knowledge, and by use-oriented research, which is essential for technical and industrial experiments and decisive to the solid existence of the μ -g program. In the words of the honorable Minister Dr. Riesenhuber (BMFT Journal no. 7, Dec. 1983), the program "Materials Research and Operations Technology" is an intelligent project for improved combined work in research and development activities, more technologically relevant system ideas and more rapid conversion of technological knowledge into marketable products. In my opinion, the μ -g related basic research is use-oriented basic research that tracks down fields of technology oriented to the future that have a high use potential. The materials research program offers conditions that can already make basic research permanently fertile.

6. WHY MOVE FROM SPACELAB TO SPACE STATION

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This question is often asked today and is answered in various ways depending on the viewpoint. The main problem here is always deciding the right point in time for the next step. In my previous remarks I have tried to give you an overview of the very promising results gained so far and to show you the scientific and technical take-off points for later industrial use of space travel. However, Germany and Western Europe do not stand alone before the new technological developments of the future. The USA and the USSR, the present great powers in space travel, have space stations already available or under construction. It is superfluous to ask the question why. These nations have a space station available for all questions of scientific and industrial use. Europe has demonstra-

ted, with the Spacelab developed and built under German industrial leadership, its capabilities and technological know-how to our partner, the USA. This is a significant condition for the offer of the American President to Europe to participate in the space station program. At present the national German u-g program in particular, but leading off from that also the corresponding European program within the framework of the European International Space Organization ESA, are at least equal in value to the programs of NASA. To refuse the offer of participation would in my opinion mean the same thing as excluding oneself from a technological development, that is bound to have important consequences for the economy of a highly technological country such as West Germany. At the same time we should ensure that the expenditures required for investment and for later operating costs remain within an economically feasible range. This appears to be the case in the currently planned degree of participation.

The task of the next few months will be to clarify both the technical problems and all the legal and administrative questions. In this circle I certainly do not need to make special mention of the fact that, relative to future industrial use of the space station, great care is required in working out the access regulations, the protection rights, the costs and many other questions.

I do not need to mention to you further that entering a technologically new world in an environment foreign to our experience requires long-term preparation. As already mentioned, West Germany has reached at least an equal level with the USA in the area of u-g research. With their strong industrial engagement, the USA and Japan have set out to overtake us and exploit the industrial uses. The programs developed so far for basic research, such as TEXUS, MAUS, D1 and D2, and the corresponding accompanying ground programs are available to German industry for its participation and use. The BMFT is prepared to provide the possibility for corresponding flights to support the equal chances of German industry. It is not necessary within the scope of this discussion to list the conditions in detail. The specifics will be determined later.

The organization of the access routes for industry is being discussed at present by the groups involved. The DFVLR is always at your disposal during the transition period.

7. SUMMARY

In my talk I have attempted to bring space travel and its possible use by industry closer to home. In so doing I have placed the main emphasis on the new area of the use of reduced gravitational effects. Thus the areas of space travel such as observation technology, communications and navigation which can already be described today as classic, could only be touched on briefly. However, the corresponding German industries are so well anchored in these areas that they no longer require a detailed exposition. I hope that my talk will contribute to a fruitful discussion today and in the future.

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